International Journal of EXERCISE SCIENCE

Original Research

Transcranial Direct Current Stimulation with the Halo Sport Does Not Improve Performance on a Three-Minute, High Intensity Cycling Test

Collin T. Garner†, Rachel M. Dykstra†, Nicholas J. Hanson‡, and Michael G. Miller‡

Human Performance and Health Education, Western Michigan University, Kalamazoo, MI, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(3): 962-970, 2021. Transcranial direct current stimulation (tDCS) uses a weak electrical current that is sent through the cerebral cortex. The Halo Sport headphones are a user-friendly form of tDCS that is implemented by many athletes purportedly to improve performance. The purpose of this study was to determine the effect of tDCS, using the Halo Sport, on performance variables associated with a high-intensity three-minute cycling test. Eighteen healthy, active individuals (ten men, eight women) volunteered for this study. The Halo Sport headphones were worn during a 20-minute warmup before completing a high-intensity three-minute cycling test. A sham treatment was used in addition to the experimental condition. Ratings of perceived exertion (RPE) were assessed every 30 seconds and electromyography (EMG) of the quadriceps muscle group was measured throughout testing. Two-way repeated measures ANOVAs were used to determine the effect of condition and time on mean RPE, heart rate (HR) and power; paired samples t-tests were also used to compare conditions. Mean HR was higher in the experimental condition (p = 0.038). Otherwise, there were no differences between conditions on any of the variables (mean RPE, cadence and speed, mean and peak HR, power, root mean square EMG). Despite the popularity of this new device, our findings do not support an ergogenic effect. However, further research is warranted.

KEY WORDS: tDCS, glycolytic, energy system

INTRODUCTION

Transcranial direct current stimulation (tDCS) is a noninvasive brain stimulation technique that alters cortical excitability and causes transient polarity-dependent shifts in the brain (28). The effects of 10 - 20 minutes of tDCS treatment have been shown to last up to 90 minutes, and may be a way of influencing the brain in an attempt to improve athletic performance (23). Some studies have shown that tDCS directly and positively influences perceived exertion (17, 24). It may also elicit performance benefits as a result of enhanced corticospinal excitability (10), or improved muscle recruitment strategies (15). However, current tDCS research targeted at improving athletic performance has shown mixed results. In a recent meta-analysis, the conclusion was drawn that tDCS has a small, but positive effect on athletic performance with a major caveat that this may be due to publication bias, as studies showing no effect are often difficult to publish (18). Additional meta-analyses have been performed and it suggested that improvements in exercise performance with tDCS are likely due to increased corticospinal excitability in the primary motor cortex (2, 13, 16). In addition, the effects of tDCS on endurance exercise are not as clear as muscular strength (19). For this reason, more studies in this area should be performed.

The traditional method of administering tDCS is somewhat time consuming, especially for new users, but allows for a greater variety of electrode placements. Typically, the subject's head is first measured in order to accurately locate the regions of interest. Thereafter, sponge electrodes, soaked in a saline solution, are securely placed on the head using a strap. Conversely, the Halo Sport (Halo Neuroscience, CA) is a simple method of administering tDCS. The device appears as a normal pair of headphones with primers spanning across the band, and plays music if desired (Figure 1). With proper placement and settings, the Halo Sport will stimulate the primary motor cortex (M1) bilaterally.

Figure 1. Halo Sport headphones (Halo Neuroscience, CA).

Two recent studies with healthy, active subjects have utilized the Halo Sport and have found improved performance. However, the methods in each study targeted the use of different energy systems. Park et al. (25) asked subjects to perform a time to exhaustion (TTE) test at a speed equivalent to 80% VO_2max, which targets the aerobic (or oxidative) system, while Huang et al. (14) used repeated six second sprints, which aims at taxing the anaerobic or high-energy phosphate system. The third and middle energy pathway, the glycolytic system, has not been investigated with the Halo Sport but is critical to exercise performance. This system uses non-aerobic breakdown of mainly stored muscle glycogen for fuel, and is highly utilized during intense exercise lasting more than a few seconds to regenerate ATP from blood glucose and stores of muscle glycogen (6). Many factors such as age, training status, and motivation affect energy system contributions, making it difficult to select a suitable test for targeting the glycolytic system (20). However, previous research has suggested that in order to substantially activate and tax this energy system, high-intensity work (>70% HR_{max}) for up to three minutes is needed (6, 12, 27). Given the lack of literature focusing on the use of Halo Sport for enhancement of activities that rely heavily upon the glycolytic energy system, research should be conducted to explore the influence of tDCS use via the Halo Sport on such activities.

The purpose of this study was to determine the effect of tDCS use via the Halo Sport on a three-minute high-intensity cycling test. It was hypothesized that the use of the Halo Sport would improve performance primarily by eliciting higher peak and mean power output, compared to a sham condition.

METHODS

Participants

Eighteen individuals (Ten men with VO_2max: 42.7 ± 4.5 ml·kg^{-1}·min^{-1}; eight women with VO_2max: 37.9 ± 3.9 ml·kg^{-1}·min^{-1}) with an average age of 24.9 ± 2.6 years and body mass index of 24.9 ± 2.6 kg·m^{-2} participated in this study. Subjects were recruited from the student recreation center on campus. In the case of any lower extremity musculoskeletal injuries or surgeries within the past six months, history of epilepsy or seizures, or metal implants in the head such as cochlear implants, individuals were not eligible to participate. The study was approved by the university's Human Subjects Institutional Review Board (Project #: 18-09-19). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (22). Upon arrival at the first visit, subjects read and signed the informed consent and were fully familiarized with the testing protocol and laboratory equipment. A health screening document procedure was used to confirm there was no more than one risk factor for cardiovascular disease (1).

Protocol

Subjects were asked to come to the laboratory for two visits: an experimental condition and a "sham" condition (single blind). The order of these conditions was counterbalanced. Each visit was separated by a minimum of 24 hours and both visits were completed within a two-week period.

During both visits, subjects completed a 20-minute warm up on the cycle ergometer (Wattbike Pro, Woodway) while wearing the Halo Sport. The Halo Sport was placed on the subjects' head after the stimulation area was cleaned with alcohol swabs, and the device's integrated electrodes were saturated with water. The associated mobile application was used to confirm a strong connection. Once this was obtained, stimulation was provided an intensity of "7" was chosen, which corresponds to a current of 1.98 mA. During the sham condition, the Halo Sport was turned on for one minute, turned off for the following eighteen minutes, and then turned back on again for the final minute. This sham methodology has been shown to produce similar perceptual responses to continuous stimulation (e.g. an itching or tingling sensation on the scalp) (11). An electromyography (EMG) electrode (Biopac, Goleta, CA) was placed on each leg, in the center of the rectus femoris muscle. Sampling frequency of the EMG system was 2000 Hz. Participants were also fitted with a chest strap heart rate monitor (Polar Electro Oy, Finland).

For the warm-up, subjects were instructed to cycle between 70-90 rpm, with two six seconds high-intensity bursts at the eight and twelve-minute marks. After completion of the warm-up, the Halo Sport headphones were removed, and the subjects had three minutes to rest prior to implementing the three-minute aerobic test (3mAT). The purpose of this test is to cycle as hard as possible for three minutes, with the goal of covering as much distance as possible in that time frame. Although simple, it is a high-intensity test. After the test was completed, the Wattbike software provided a maximal oxygen uptake (VO_2max) value using a previously validated prediction equation (26). Ratings of perceived exertion (RPE) were assessed every 30 seconds using the Borg 6-20 scale (8). Similar verbal encouragement was provided throughout each test. The root mean square of the raw EMG signals was calculated at the end of the study using the Biopac software (*Acq*Knowledge 4.4), which uses a 30ms sliding time window method.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics (Version 24; IBM, Armonk, NY). Paired samples t-tests were performed to compare experimental and sham conditions. The primary dependent variables were RPE, cadence, distance, and speed, as well as mean and peak heart rate (HR), power, and root mean square EMG. Additionally, 2 (condition) x 6 (time as the mean of each 30 second period) repeated measures analyses of variance (rmANOVAs) were used to determine the effect of the stimulation on mean RPE, HR, and mean and peak power. Greenhouse-Geisser corrections were used when the assumption of sphericity was violated. Significance level was set *a priori* at $p < 0.05$.

RESULTS

There were no differences in mean power ($F(1,16) = 0.709$, $p = 0.412$, $\eta_p^2 = 0.042$) or peak power ($p = 0.734$, $d = 0.081$) between conditions. The condition*time interaction was also not significant ($F(1.14,18.19) = 0.096$, $p = 0.792$, $\eta_p^2 = 0.006$). Figure 2 shows the mean power for every subject in each condition over the entire 3mAT. Figure 3 shows the mean power over each 30-second time period. Mean HR over the entire 3mAT was significantly higher in the experimental condition ($p = 0.038$, $d = 0.551$). However, the rmANOVA for HR averaged every 30 seconds showed that there was no condition effect ($F(1,15) = 4.17$, $p = 0.059$, $\eta_p^2 = 0.217$) and no condition*time interaction ($F(2.04, 30.57) = 0.804$, $p = 0.459$, $\eta_p^2 = 0.051$). There were no other differences between conditions on the Wattbike variables (Table 1). There were also no differences between the sham and experimental conditions on any of the EMG variables (Table 2).

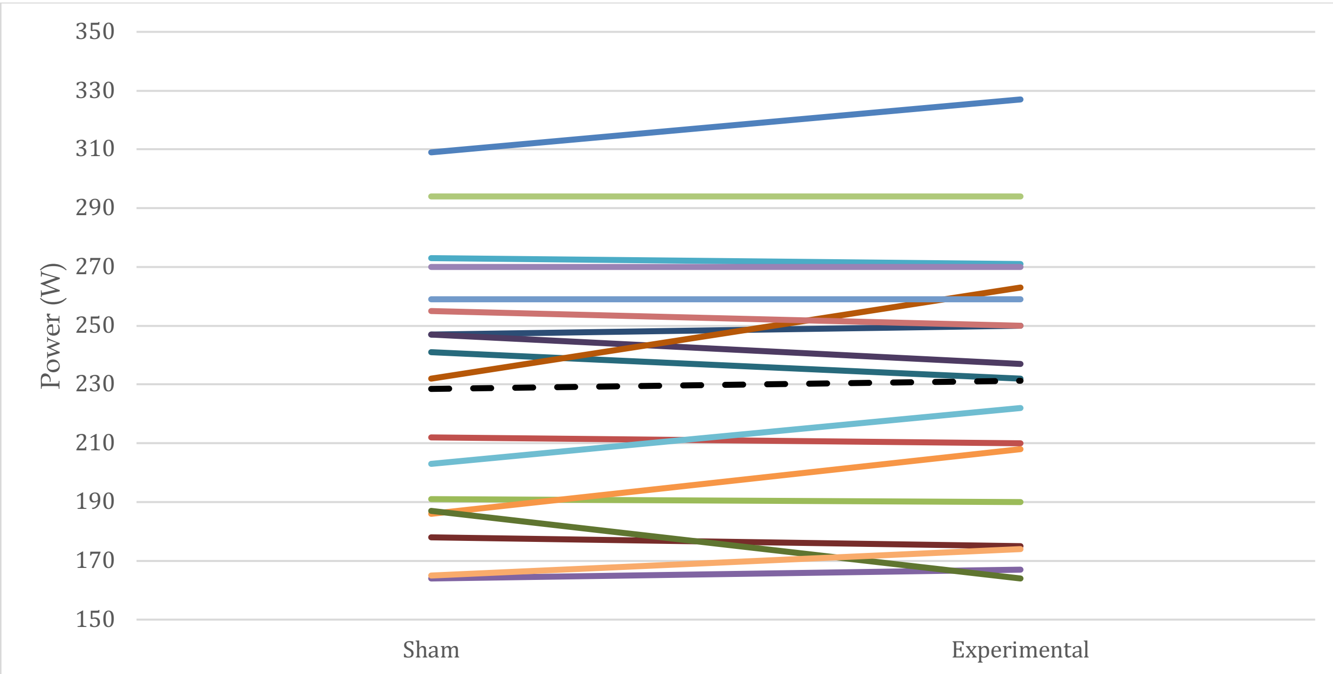

Figure 2. 3mAT mean power output of each subject for both conditions. Bold dotted line represents the group mean.

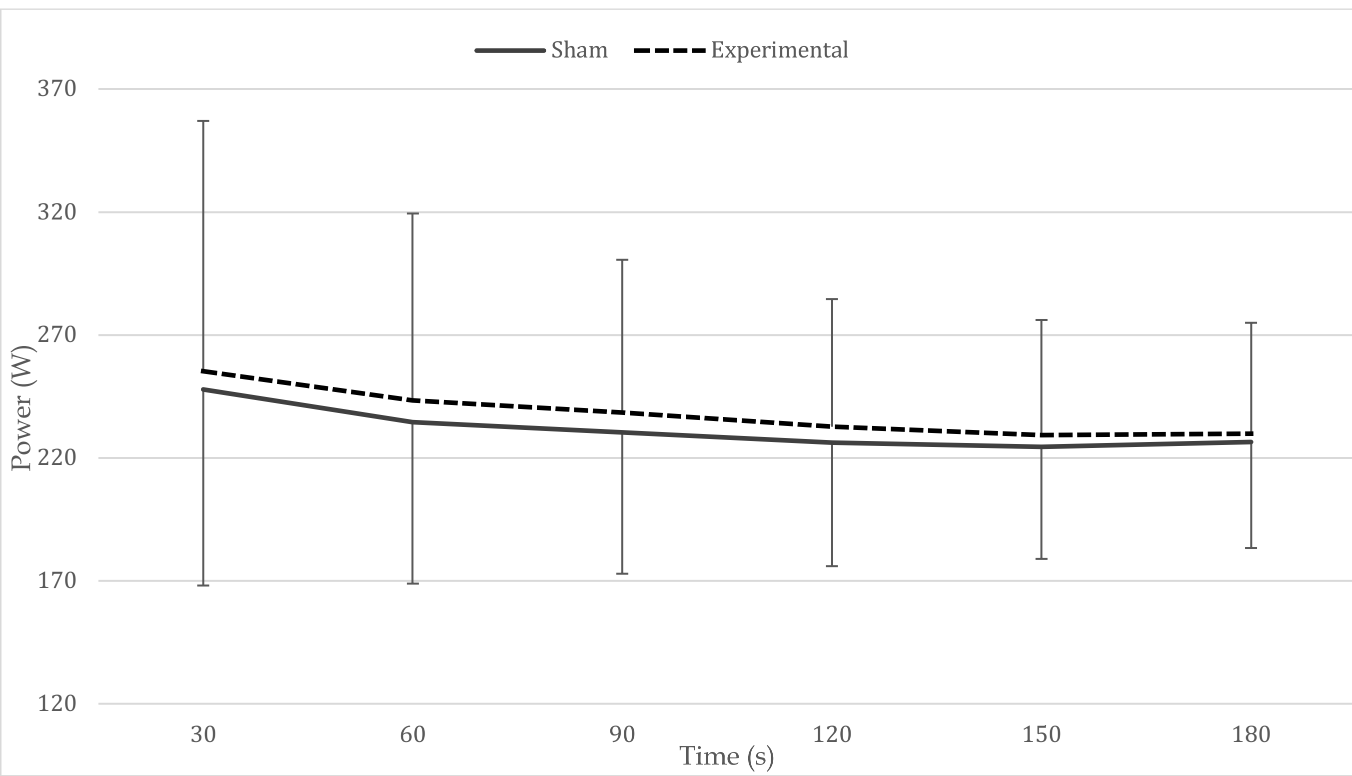

Figure 3. 3mAT mean power over each 30-second period.

Table 1. Wattbike variables.

	Sham	Experimental	*p*	*d*
Mean Cadence (rpm)	107.6 ± 7.9	108.4 ± 7.6	.404	.194
Mean Speed (km ·hr^{-1})	38.5 ± 2.8	38.7 ± 2.9	.403	.223
Total Distance (m)	1,922.4 ± 139.9	1,931.1 ± 142.4	.414	.197
Mean HR (bpm)	159.4 ± 18.8	162.1 ± 17.2	.038*	.551
Peak HR (bpm)	179.6 ± 18.8	180.2 ± 19.6	.550	.153
Mean Power (W)	228.5 ± 44.4	231.3 ± 46.4	.375	.216
Peak Power (W)	436.8 ± 136.1	427.4 ± 193.4	.734	.081

Values are presented as mean ± SD. Effect size given as Cohen's *d* (small: 0.2, medium: 0.5, large: 0.8). * denotes statistically significant *p* values.

Table 2. Electromyography results.

	Sham	Experimental	*p*	*d*
L leg mean (mV)	.161 ± .080	.175 ± .108	.389	.216
L leg peak (mV)	.276 ± .185	.281 ± .188	.851	.047
R leg mean (mV)	.216 ± .222	.173 ± .069	.393	.216
R leg peak (mV)	.337 ± .346	.298 ± .211	.365	.223

Values are presented as mean ± SD. Effect size given as Cohen's *d* (small: 0.2, medium: 0.5, large: 0.8).

No differences in RPE were seen between conditions ($p > 0.05$, for all time points), but there was a significant effect of time ($F(1.68,26.89) = 165.1$, $p < 0.001$, $\eta_p^2 = 0.912$), as RPE increased linearly. The average RPE was 16.0 ± 0.3 in the sham condition and 15.9 ± 0.3 in the experimental (p = 0.610). Peak RPE values were 19.0 ± 1.2 and 19.0 ± 1.3 for the sham and experimental conditions, respectively ($p = 1.000$, $d = 0.000$). The interaction between condition*time was not significant ($F(2.28,36.43) = 0.439$, $p = 0.673$, $\eta_p^2 = 0.027$).

There was no difference between conditions for predicted VO_2max, so the higher of the two conditions is provided for descriptive data (sham: 39.89 ± 4.8 ml ·kg^{-1} ·min^{-1}; experimental: 40.4 ± 5.1 ml ·kg^{-1} ·min^{-1}).

DISCUSSION

The current study showed that tDCS use via the Halo Sport was not associated with improved performance on a three-minute high-intensity cycling test, as evidenced by no differences in mean or peak power. Contrary to the present findings, two recent studies demonstrated significant improvements in exercise performance associated with the use of Halo Sport. Park et al. (25) found an improvement in TTE after subjects received 20 minutes of stimulation from the Halo Sport. During a TTE test, the dominant energy system was the aerobic system, as exercise exceeded 180 seconds in duration (20). Huang et al. (14) targeted the immediate energy system (high-energy phosphates) using a repeated 6-second sprint protocol on a cycle ergometer. After 20 minutes of simulation with the Halo Sport, they also observed a significant increase in performance, specifically mean peak power output.

A recent review on the ergogenic effects of tDCS (4) described a negative relationship between baseline muscle strength and the magnitude of change elicited by tDCS. This suggests that subjects with relatively low levels of strength may see a greater benefit from tDCS. Muscle strength was not measured, but some data regarding aerobic capacity can be provided. Huang et al. (14) had male subjects with a mean VO_2max of 54.0 ± 5 ml $\cdot kg^{-1} \cdot min^{-1}$. Our male subjects had a mean VO_2max of 42.7 ± 4.5 ml $\cdot kg^{-1} \cdot min^{-1}$, which is considerably lower. In the Park et al. study (25), aerobic capacity was not assessed. Huang et al. (15) showed a performance benefit from tDCS, but the current study did not. Unlike those with relatively lower strength levels who may receive greater benefit from the use of tDCS, it is plausible that those with relatively lower aerobic capacity may not experience the same benefit. Further studies are warranted to determine the effect of fitness on the effectiveness of tDCS. An ideal study would include testing of multiple fitness variables to determine how they moderate the relationship between tDCS and athletic performance.

In the present study there were no differences in EMG activity between conditions. Similarly, Ciccone et al. (9) compared anodal and sham tDCS conditions used before a maximal isokinetic work test and found no differences in peak work or EMG. Angius et al. (5) found a significantly longer time to failure in a cycling test after tDCS, but no differences were seen in EMG activity when comparing conditions. These studies used predetermined workloads for testing protocols. However, during the 3mAT, the workload is constantly adjusted in order to execute an optimal pacing strategy and inhibit fatigue (3). Moreover, a constant workload is not maintained throughout the duration of the test, making it difficult to compare the effects of treatment on physiological responses during exercise (3). Additionally, with a lack of observed differences for both constant and changing workloads, it is possible that tDCS is unable to elicit acute neuromuscular alterations during exercise.

Lastly, there were no differences in mean or peak ratings of perceived exertion between the conditions, which corroborates other studies (7, 21). In the current study, electrode placement was over the motor cortex. Baldari et al. (7) also targeted this region using tDCS before an incremental test to exhaustion. They found no performance benefit, and no RPE differences between conditions. Although Park et al. (25) showed a performance improvement with tDCS, they did not see any differences in RPE between conditions. Conversely, Okano et al. (24) reported a slower rise in RPE during an incremental exercise test to exhaustion after tDCS. Unlike previous studies, their placement of electrodes targeted the insular cortex, not the motor cortex (24). Stimulation of this region of the brain has been shown to be analgesic, and it may be the reduction in discomfort during exercise that resulted in a decreased RPE (24). Regardless of electrode placement, the ability of tDCS to decrease RPE seems to be equivocal and elusive (4).

Many sports teams at various levels are utilizing the Halo Sport during practice sessions. It was found that its use during a warm-up was not associated with improved performance on an intense cycling test. RPE and muscle activity were also not influenced. Despite the popularity of this new device, our study does not support an ergogenic effect of tDCS applied to the motor cortex via the Halo Sport. However, more studies should be performed in order to fully understand the potential ergogenic benefits of this intervention. The targeted energy system and fitness level are independent variables that may influence the efficacy of the stimulation with the Halo Sport. Additionally, training studies should be completed to determine if a longer period of use is needed to elicit performance benefits.

REFERENCES

1. ACSM. American college of sports medicine's exercise testing and prescription. Philadelphia, PA: Lippincott Williams & Wilkins; 2017.

2. Alix-Fages C, Romero-Arenas S, Castro-Alonso M, Colomer-Poveda D, Río-Rodriguez D, Jerez-Martínez A, Fernandez-del-Olmo M, Márquez G. Short-term effects of anodal transcranial direct current stimulation on endurance and maximal force production: A systematic review and meta-analysis. J Clin Med 8(4): 536, 2019.

3. Amann M, Hopkins WG, Marcora SM. Similar sensitivity of time to exhaustion and time-trial time to changes in endurance. Med Sci Sports Exerc 40(3): 574-578, 2008.

4. Angius L, Hopker J, Mauger AR. The ergogenic effects of transcranial direct current stimulation on exercise performance. Front Physiol 8: 90, 2017.

5. Angius L, Mauger AR, Hopker J, Pascual-Leone A, Santarnecchi E, Marcora SM. Bilateral extracephalic transcranial direct current stimulation improves endurance performance in healthy individuals. Brain Stimul 11(1): 108-117, 2018.

6. Baker JS, McCormick MC, Robergs RA. Interaction among skeletal muscle metabolic energy systems during intense exercise. J Nutr Metab 2010: 905612, 2010.

7. Baldari C, Buzzachera CF, Vitor-Costa M, Gabardo JM, Bernardes AG, Altimari LR, Guidetti L. Effects of transcranial direct current stimulation on psychophysiological responses to maximal incremental exercise test in recreational endurance runners. Front Psychol 9: 1867, 2018.

8. Borg GA. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med 2(2): 92-98, 1970.

9. Ciccone AB, Deckert JA, Schlabs CR, Tilden MJ, Herda TJ, Gallagher PM, Weir JP. Transcranial direct current stimulation of the temporal lobe does not affect high intensity work capacity. J Strength Cond Res 33(8): 2074-2086, 2018.

10. Cogiamanian F, Marceglia S, Ardolino G, Barbieri S, Priori A. Improved isometric force endurance after transcranial direct current stimulation over the human motor cortical areas. Eur J Neurosci 26(1): 242-249, 2007.

11. Gandiga PC, Hummel FC, Cohen LG. Transcranial dc stimulation (tdcs): A tool for double-blind sham-controlled clinical studies in brain stimulation. Clin Neurophysiol 117(4): 845-850, 2006.

12. Gastin PB. Energy system interaction and relative contribution during maximal exercise. Sports Med 31(10): 725-741, 2001.

13. Holgado D, Vadillo MA, Sanabria D. The effects of transcranial direct current stimulation on objective and subjective indexes of exercise performance: A systematic review and meta-analysis. Brain Stimul 12(2): 242-250, 2019.

14. Huang L, Deng Y, Zheng X, Liu Y. Transcranial direct current stimulation with halo sport enhances repeated sprint cycling and cognitive performance. Front Physiol 10: 118, 2019.

15. Krishnan C, Ranganathan R, Kantak SS, Dhaher YY, Rymer WZ. Anodal transcranial direct current stimulation alters elbow flexor muscle recruitment strategies. Brain Stimul 7(3): 443-450, 2014.

16. Lattari E, Oliveira BR, Junior RSM, Neto SRM, Oliveira AJ, Neto GAM, Machado S, Budde H. Acute effects of single dose transcranial direct current stimulation on muscle strength: A systematic review and meta-analysis. PloS One 13(12): e0209513, 2018.

17. Lattari E, Rosa BF, Fonseca SJ, Murillo-Rodriguez E, Rocha N, Machado S, Maranhão GN. Effects on volume load and ratings of perceived exertion in individuals advanced weight-training after transcranial direct current stimulation. J Strength Cond Res 34(1): 89-96, 2018.

18. Machado DGdS, Unal G, Andrade SM, Moreira A, Altimari LR, Brunoni AR, Perrey S, Mauger AR, Bikson M, Okano AH. Effect of transcranial direct current stimulation on exercise performance: A systematic review and meta-analysis. Brain Stimul 12(3): 593-605, 2018.

19. Machado DGdS, Unal G, Andrade SM, Moreira A, Altimari LR, Brunoni AR, Perrey S, Mauger AR, Bikson M, Okano AH. Effect of transcranial direct current stimulation on exercise performance: A systematic review and meta-analysis. Brain Stimul 12(3): 593-605, 2019.

20. Maud PJ, Foster C. Physiological assessment of human fitness. Champaign, IL: Human Kinetics; 2006.

21. Montenegro RA, Farinatti PT, de Lima PF, Okano AH, Meneses AL, de Oliveira-Neto L, Cavalcante BR, de A Correia M, Fontes EB, Ritti-Dias RM. Motor cortex tdcs does not modulate perceived exertion within multiple-sets of resistance exercises. Isokinet Exerc Sci 24(1): 17-24, 2016.

22. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

23. Nitsche MA, Paulus W. Sustained excitability elevations induced by transcranial dc motor cortex stimulation in humans. Neurology 57(10): 1899-1901, 2001.

24. Okano AH, Fontes EB, Montenegro RA, Farinatti Pde T, Cyrino ES, Li LM, Bikson M, Noakes TD. Brain stimulation modulates the autonomic nervous system, rating of perceived exertion and performance during maximal exercise. Br J Sports Med 49(18): 1213-1218, 2015.

25. Park S-B, Sung DJ, Kim B, Kim S, Han J-K. Transcranial direct current stimulation of motor cortex enhances running performance. PloS One 14(2): e0211902, 2019.